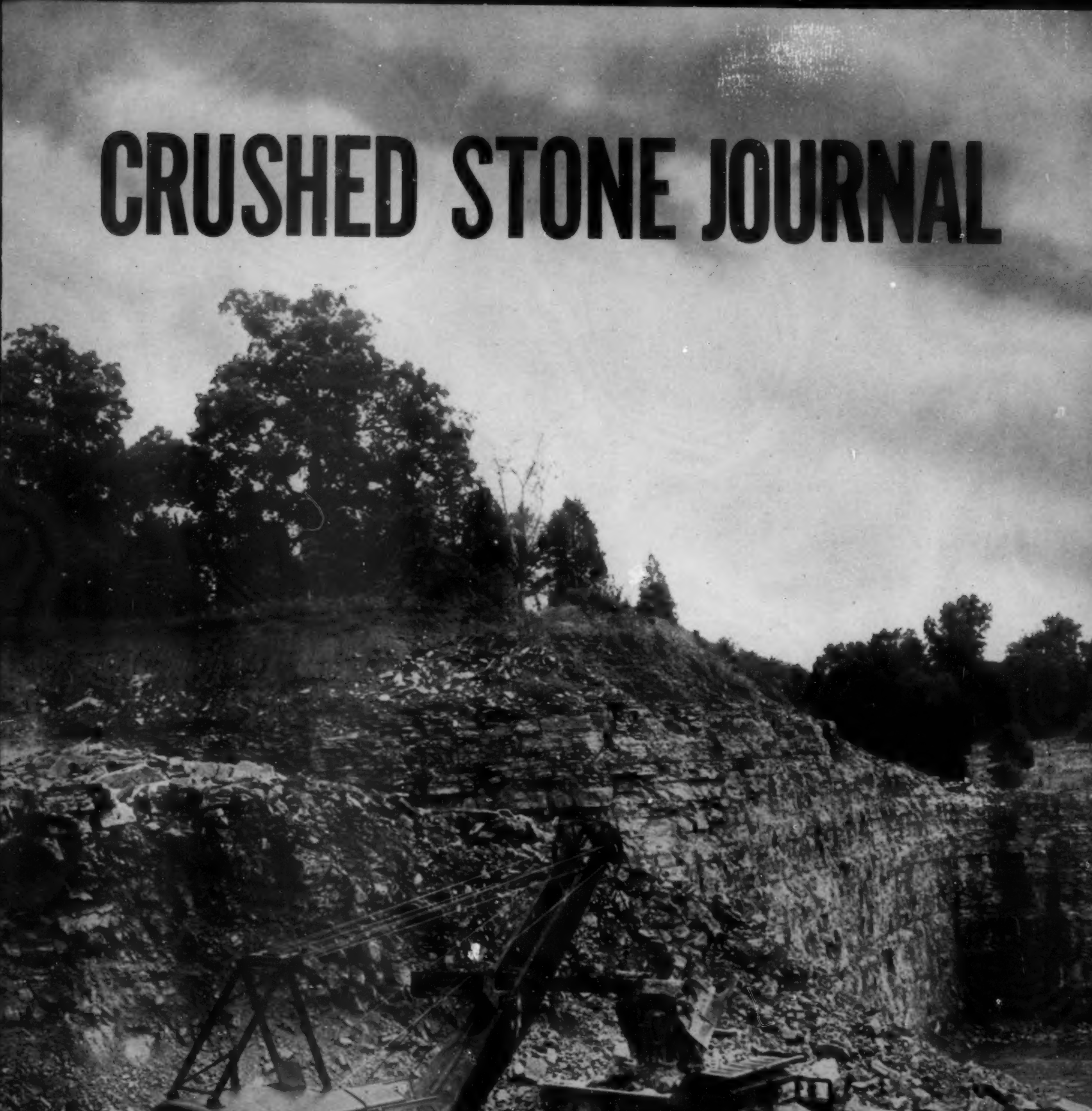
CRUSHED STONE JOURNAL



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45th ANNUAL CONVENTION

NATIONAL CRUSHED STONE ASSOCIATION

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Crushed Stone Journal

Official Publication of the NATIONAL CRUSHED STONE ASSOCIATION

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NATIONAL CRUSHED STONE ASSOCIATION

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Contents

Cover Photograph—Hermitage Quarry of Lambert Bros. Division, Vulcan Materials Company, Donaldson, Tennessee

Oscar Edwin Benson
1898-1961

It is with sadness in our hearts and a profound sense of loss that we record the sudden and tragic death of Oscar E. Benson, beloved past president of the National Crushed Stone Association and president of the General Crushed Stone Company, Easton, Pennsylvania, on April 6, 1961.

Ben, as he was affectionately known to his host of friends in the crushed stone industry, was on a routine visit to a couple who lease a house from the Company located near its Glen Mills, Pennsylvania, plant. Ben was removing his overcoat to go inside when he was stricken. The husband, a doctor, rendered immediate aid and was joined within minutes by another doctor who had been called. In this short time Ben had passed on, with death caused by a cerebral hemorrhage.

Ben first became active in the affairs of the National Crushed Stone Association when he was elected to its Board of Directors in 1952, subsequently serving on its Executive Committee, and as Regional Vice President for the Eastern Region. In 1958 he was elected President, the highest honor within the power of the Association to bestow.

Oscar Benson rendered outstanding service to the National Crushed Stone Association in the several capacities in which he served — the warmth of his smile and graciousness of manner endeared him to all who had the privilege of calling him their friend. We shall sorely miss him in the counsels of NCSA.

Ben's interests ran far afield from the crushed stone industry and were invariably prompted by his deep and sincere desire to be helpful to his fellow man. He served as trustee of the Easton Hospital; was a director of the Hospital Service Plan of the Lehigh Valley and gave generously of his time to Community Chest activities.

Mr. Benson is survived by his widow, the former Olivette Saltsman, two sons, two brothers, three sisters, and four grandchildren.

To the members of his family and business associates we extend heartfelt sympathy in their great loss.

Specifications for Mineral Aggregates*

By J. E. GRAY
Engineering Director
National Crushed Stone Association
Washington, D. C.

BEFORE specifications are discussed it may be well to define the term "Mineral Aggregates." Professor K. B. Woods[1] defined *"Mineral Aggregate*—An aggregation of sand, gravel, crushed stone, slag, or other material of mineral composition used in combination with a binding medium to form bituminous and portland cement concrete, macadam, mastic, mortar, plaster, etc., or alone as in railroad ballast, filter beds, and various manufacturing processes, such as fluxing, etc." This definition is too all inclusive for the purposes of this paper; therefore, this discussion will be confined to specifications for natural aggregates, which means sand and gravel and crushed stone, and limited primarily to coarse aggregate which is aggregate larger than 1/4 in. in size.

To the uninitiated, this may seem to be a very limited subject on an unimportant material. However, aggregates are essential in all types of construction. The tonnage and value of these two aggregates produced in the United States during 1959 as reported by the Bureau of Mines were as follows:

Sand and Gravel	729,895,000 tons	valued at $728,527,000
Crushed Stone	581,721,000 tons	valued at $824,411,000

A rough estimate would be that about 60 per cent of this tonnage is coarse aggregate.

The largest use of aggregates is for highway construction. Furthermore, the majority of sales for other than highway uses is dependent upon compliance with state highway specifications because it is widely accepted that, if an aggregate is satisfactory for state highway uses, it will be safe for almost any other construction purpose. It, therefore, is essential for an aggregate producer to have a source of material that meets the specifications of the state highway department and to take all necessary steps in the processing to prevent the stigma of rejection.

*Presented at the Annual Meeting of the American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., St. Louis, February 26-March 2, 1961

Aggregates are fundamentally a heavy bulky commodity of low value per ton; hence, availability and economic considerations limit their shipment to relatively short distances. They are produced in all states in varying quantity and quality. Originally, most of the state highway departments developed specifications for aggregates on the theory of obtaining the best aggregate economically available, and of specifying such a standard of quality that the material furnished would be suitable for all types of construction such as paving, structures, surface treatments, bases, etc. This accounts for the wide divergence in quality requirements of aggregates in different areas for the same use. Also, this policy gave encouragement to the development of the aggregates industry in each state due to the potential of a large and continuing market.

For many years the primary quality requirements for aggregates were that it should possess adequate resistance to wear or abrasion and to weathering. The minor quality requirements were generally covered in an opening statement to the effect that it should be free of such material as dust, dirt, clay balls, flat and elongated pieces, chert, shale, soft pieces, and other deleterious material. The enforcement of properties covered in such a general statement was left to the judgment of the engineer who did not exercise this prerogative unless there was an obvious excessive amount of objectionable material present. This quality phrase of the specifications was considered perfunctory; consequently, aggregate quality meant, for the most part, compliance with the requirements for abrasion resistance and soundness.

Research and field performance studies have increased the knowledge of the behavior of aggregates and this knowledge has gradually been written into specifications with the result that today to maintain one's competitive position the economical production of aggregate which complies with a rigid specifications is a real challenge.

Now, let us discuss these specific requirements in some detail.

All specifications for materials consist of two parts; one, a statement of the quality requirements and, two, a reference to the methods of tests to be used for measuring compliance. Individuals interested in bidding on a proposal to supply material generally read and understand the quality requirements and pay little attention to the references on methods of tests. In fact, many specification writers have little appreciation of the significance of methods of testing or the effect of revisions of accepted test procedures which are a continuing activity of the American Society for Testing Materials. This has led to vague specifications with their controversial problems of interpretation. The Los Angeles abrasion test and the sulfate soundness test are cases in point which will be described later. The subject of specifications for mineral aggregates must include, therefore, a discussion of the significance of the methods of tests.

Abrasion Test

Probably the first abrasion test was the Deval test, developed in France in 1878 and is still used by a few state highway departments. This test consists in subjecting a sample weighing 5,000 grams to 10,000 revolutions in a tumbling barrel and determining the amount of material passing the No. 12 sieve as the percentage of wear. There are two ASTM methods of making the Deval test: one, ASTM D 289 is for graded coarse aggregate which includes gravel, crushed gravel, crushed stone, and crushed blast furnace slag; and the other, ASTM D 2 is for rock. The test sample for gravel is a graded sample to which is added a charge of six 1 7/8 in. steel balls, and for stone the sample consists of 50 cubical pieces hand broken from ledge rock with no charge of steel balls. Test results are not comparable between the two types of aggregate. The Deval test has been almost completely replaced by the Los Angeles test; however, the few states still using the Deval test probably will not change for a long time because the correlation between the two tests is not good with aggregates of certain mineral compositions. The Los Angeles abrasion test, described in ASTM C 131, consists in subjecting a graded sample from the commercial product to 500 revolutions in a steel drum which has a radial shelf projecting on the inside that picks up the sample with a steel charge of a specified number of 1 7/8 in. balls and lets it drop as the shelf rotates for 500 revolutions. Per cent loss is determined by the amount passing the No. 12 sieve. The advantages of this test are that the graded commercial product is tested, the test can be made easily and quickly, and results are comparable between different types of aggregate.

It is likely that the first question which comes to mind is that if this Los Angeles test is so advantageous, why does not everyone use it. This brings us to the heart of our subject "Specifications." The aggregates industry has developed under a specification which requires a Deval loss of not more than, say, 6 for crushed stone and 10 for gravel. Also, the performance or service record of materials as supplied was good. The problem is how to change to the Los Angeles abrasion test without opening up the specifications to inferior materials or making them more restrictive so as to reject presently acceptable material. Woolf[2] shows a curve which gives the correlation between the two abrasion tests for both types of aggregate—both these curves are averages. There are many individual sources of aggregate which do not correlate as well as these curves would indicate. In states where the aggregate sources are reasonably uniform as to mineral type, there has been no trouble in adopting the Los Angeles test, but in states where there is trap, granite, limestone, and other rock types, it has not been possible to adopt the Los Angeles without causing a change in standards of acceptance.

Of course, any change in methods of test for acceptance or specification limits is watched by individuals in the industry to determine how it affects their businesses. If the effect is to tighten specifications and the producer is within safe limits, the change is considered good. While, on the other hand, if the effect is to relax specifications and to allow for greater competition, it is not so good.

Today, the Los Angeles abrasion test is required by 43 states and the Bureau of Public Roads for acceptance of aggregates. A review of these specifications reveals that the maximum allowable loss varies from 25 per cent for surface treatment stone in Connecticut to 65 per cent for portland cement concrete in South Carolina. The problem from a production point of view is not the range from state to state, but the range in a given state

for the various types of construction. For example, Florida sets a limit of 40 per cent loss for portland cement concrete, bituminous plant mixes—base and surface, stone bases, and surface treatments; thus it is obvious that if one had a source of aggregate having a Los Angeles loss of less than 40 per cent, he could enjoy a market for his aggregate in all types of construction. On the other hand, Texas sets a limit of 45 per cent loss for portland cement concrete, 40 per cent for bituminous bases, and 35 per cent for bituminous surface courses and surface treatments, and this test is not required for base course material. In order to supply aggregate for all types of construction, material with a Los Angeles loss of less than 35 per cent would be necessary. Suppose a high quality source is located which has a Los Angeles loss of, say, 15 to 20 per cent but the stone is hard and abrasive so is costly to produce. Such aggregate cannot compete with local production of aggregate that is easy to process with little wear on equipment which just comes within the specifications on Los Angeles abrasion loss.

Before opening up a new source of aggregate, it is extremely desirable to know the limits on Los Angeles abrasion loss for the various types of construction and to obtain as much information as possible to predict the most probable trends in type of construction. Since no premium is given for producing a better quality aggregate than required by the specifications and since better quality generally means a more costly aggregate to produce, the ideal aggregate, from a production point of view, is one that is just safely within the specifications. A very interesting illustration of the effect of specification limits on Los Angeles abrasion loss has occurred repeatedly in the construction of flexible pavements in the Interstate System. Generally, specifications for Los Angeles abrasion on base course material are 10 to 25 percentage points higher than for aggregate in the binder and surfacing courses. A number of established producers who had suitable material for base and surface courses found that they could supply only surfacing aggregate because the contractors were able to produce their own base material from roadside deposits much more economically under this difference in Los Angeles requirements. While the Los Angeles abrasion test has been correlated with performance in service by such researches as Woolf's[3] whose work indicated that the modulus of rupture and the compressive strength of concrete decreased with increases in the per cent of wear, and Goldbeck,[4] who concluded that the Los Angeles test agrees exceptionally well with service behavior as indicated by crushing under a roller, the fact is that the range in allowable loss in specifications for various types of construction can only indicate that the policy of the state highway departments is to set the limits to obtain the best aggregate economically available that gives satisfactory performance. Thus, in the granite producing states of North Carolina, South Carolina, and Georgia, the limit on Los Angeles loss is 55, 65, and 60 per cent for portland cement concrete; in the limestone producing states of Indiana, Illinois, Kentucky, and Tennessee, the allowable loss is 35, 40, 40, and 40; and in the trap rock producing states of Connecticut and Massachusetts, the maximum allowable loss is 40 per cent for portland cement concrete but 25 per cent for bituminous surface courses. The granites with their high Los Angeles losses perform exceptionally well in concrete pavements while a limestone with the same high loss would probably be chalky or have a high clay or shale content which would render it unsuitable because of lack of soundness. The trap rocks have been able to maintain their position with respect to bituminous surface because of proven superior performance of the exposed and unsupported stone; however, in portland cement concrete they have had to give way to aggregates with higher Los Angeles losses due to the fact that aggregates locally available with losses up to 40 per cent have performed satisfactorily.

Soundness

All aggregate specifications have a requirement for soundness where weathering is a problem. The acceptance test most often referred to is the sodium or magnesium sulfate soundness test which is empirical, lacking in precision, has not been correlated with field performance, and has not been accepted as an ASTM standard. Nevertheless, thirty-four states use it as an acceptance test. A typical specifications is ASTM C 33-57 for Concrete Aggregates which states in part—"Coarse aggregate subjected to five cycles of the soundness test shall show a loss, weighted in accordance with the grading of a sample complying with the designated limitations set forth

in Section 7, not greater than 12 per cent when sodium sulfate is used or 18 per cent when magnesium sulfate is used." Section 7 referred to gives nine sizes or gradings used in concrete, ranging from 3 1/2 to 1 1/2 in. down to 3/4 in. to No. 4, which must comply with the one value in the specifications. Woolf[5] says "It is quite unusual for different sizes of a sample of aggregate to have the same or nearly the same loss in the sulfate soundness test. Consequently, samples of one aggregate prepared with three different gradings may have markedly different losses." The limit of 12 or 18 per cent loss implies a precision in testing and an interpretation of results as to satisfactory and unsatisfactory material that is completely unwarranted.

The widely used acceptance test, ASTM C 88-56T, Tentative Method of Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate, was first issued in 1931. After almost 30 years of use, it is still a tentative method. There is a statement in the scope of the method that spells out the intent, yet it has been ignored by all specification writers. The statement is: "It furnishes *information helpful in judging* the soundness of aggregate subject to weathering action, particularly when adequate information is not available from service records of the material exposed to actual weathering conditions." Actually, the intent of the test is that it should serve as a warning of need for further investigation if an aggregate should show a high loss.

While reliance on service records is frequently advocated in ASTM methods of test, rarely is it used in practice. Aggregates must comply with the specifications on the basis of acceptance test results. Bloem[6] says: "The lack of more dependable methods has led specifying agencies to put inflexible limits on soundness loss and to disregard the need for engineering judgment in the interpretation of the test results. These arbitrary limits have caused rejection of highly acceptable aggregates and permitted acceptance of materials that contributed to extensive concrete disintegration." Naturally, the question must come to mind that if this sulfate test gives misinformation, why is it in such extensive use. Since unsound aggregate does cause serious distress in concrete, there is great need for a quick test to evaluate this property of an aggregate before it is used. In spite of all of its shortcomings, the sulfate soundness test is the best available method of test for making a quick evaluation. While a soundness test of an aggregate by a procedure of incorporating it in air entrained concrete and measuring the length of time that it remains immune to freezing while continuously exposed to moisture holds much promise,[7] [8] the fact is the sulfate soundness test is the test that producers must contend with for the foreseeable future.

The production problems associated with specifications on soundness are different for the two types of natural aggregate, gravel and crushed stone.

As good deposits of gravel become depleted, there has been a need to recover the good gravel from marginal deposits which had been bypassed as uneconomical. Large gravel deposits in the Ohio River were badly contaminated with coal of lower specific gravity than the gravel, which led the Dravo Corporation[9] to install, in 1951, the first heavy media separation plant for the beneficiation of gravel in this country. Gravel has been upgraded not only by removal of coal but also by the removal of unsound material such as shale, chert, and soft pieces of low specific gravity. Since 1951, heavy media separation or jigs have been used increasingly for the beneficiation of gravel wherever there can be effected an economical separation of sound and unsound material on the basis of a differential in specific gravity. Before a decision can be made on any system of beneficiation, a careful and complete study must be made of the properties of the material, the tonnages of good gravel recovered, of poor material removed, and of good gravel carried over with the bad, as well as of plant design, capital cost, and operating cost. Gravel is a relatively low priced product so any large capital investment that increases cost must be justified. Heavy media separation as reported by F. J. Lloyd[10] of Dravo Corporation after 5 years of operation cost 15.1 cents per ton. The widespread use of beneficiation in the gravel industry has been possible because gravel is composed of discrete particles of different quality with the necessary difference in specific gravity.

For crushed stone, let us first consider a hypothetical case of a quarry having a 100 ft face with two separated strata each 5 ft thick of unsound rock. A soundness test on a truly representative sample would show a 10 per cent loss and the

stone complies with the specifications. Later a structure shows distress with the trouble being attributed to the use of unsound stone. An investigation reveals the two unsound ledges and the producer is told that the stone from his quarry will not be used until the two ledges have been removed from production. Aside from the matter of drilling, blasting, and discarding ten per cent of the rock, there is the problem of the best procedure to develop benches, say, with 30, 20, and 40 ft working faces with equipment designed for efficient operation with the 100 ft face. Any producer of aggregate whose material approaches the limits of the soundness requirements runs the risk that at some time there may occur a concentration of the unsound particles, to the extent that it will cause distress and then the offending material must be removed from the finished product. These are production problems brought about by a false sense of security in numbers written in specifications which have been based on unreliable information that, in the end, required the use of engineering judgment.

Up to the present time, beneficiation has been rarely used in crushed stone production because either there is not enough difference in specific gravity between sound and unsound material or else the unsound material was not in discrete particles but was an adhering contaminant of the sound stone. Beneficiation does hold promise for the economic removal of low gravity, unsound chert to within tolerable limits.

Shape of Particle

The foregoing discussion of abrasion and soundness encompasses the vital considerations that affect the very life of an aggregate operation. There are other requirements of specifications that must be met but may be thought of as secondary since they hardly ever necessitate the abandonment of an operation, but do have an effect on the efficiency and cost. These are shape of particle, deleterious substances, and gradation.

Specification requirements on shape of particle for crushed stone have been a source of great concern for the past few years. For years, the general statement that stone shall be free of flat and elongated pieces was in all specifications. Then, complaints became numerous on the lack of proper workability of concrete due to excessive amounts of poorly shaped stone. Goldbeck[11] investigated this problem and reported "Flat and elongated pieces to a small extent increase the percentage of voids in stone aggregate and probably to a slight extent decrease the workability of the concrete—however, a considerably greater increase in voids takes place due to variations in gradation which may produce much harsher workability than produced by flat and elongated pieces. Flat pieces up to 10 per cent in 1:2:4 mixtures or 15 per cent in 1:2:3 1/2 mixtures do not decrease the strength of the concrete." However, one highway department wrote specifications to the effect that not more than 5 per cent flat and elongated pieces, ratio of maximum length to average thickness of 5:1, shall be permitted on sizes retained on the 1 in. sieve. This was a very restrictive requirement that caused a number of producers to install additional crushers to make acceptable aggregate.

There has been a trend in specification writing to eliminate general descriptive phrases as much as possible by writing in definite numerical limits. Kaerby,[12] as a result of his researches on surface treatments, reported that flat and elongated pieces were objectionable in this type of construction which involves aggregate smaller than 1 in. in size. Soon many specifications required that aggregate shall not have more than a stated percentage of flat or elongated pieces which covered all sizes. A review of state highway specifications reveals limits on allowable flat or elongated pieces ranging from 3 to 20 per cent. A basic fact in crushing is that the greater the reduction ratio, the higher the amount of flat or elongated pieces produced. Unpublished data obtained in our laboratory indicated that as the sizes became smaller, the percentage of flat and elongated pieces increased. Subcommittee C-12 of Committee D-4 of ASTM on Surface Treatments made a survey of the state highway departments last year to obtain data or experience statements as to what should be the limitation on shape of particle for this type of construction. The data from this survey formed the basis of a recommendation that was accepted and should appear in the revised specification. The recommendation was: "Aggregate retained on the 3/8 in. sieve shall not have more than 10 per cent flat or elongated pieces in which the ratio of the maximum to the minimum dimensions of its circumscribing rectangular prism is greater than 5." In time, this recommendation should bring more uniformity to specifications for shape of particle.

The task of producing better shaped stone is not as simple as some believe it to be, for the thought has been expressed that all one has to do is to install impact crushers. It is true that impact crushers produce well shaped stone, but their efficient use is limited to rock with not more than 5 per cent silica. The problem of improving the shape of particle usually occurs with hard stone where other types of crushers are used. A study should be made of the existing product to determine where to install a crusher to change the reduction ratio to effect the necessary improvement in the sizes under consideration. Once this is done, then the design must be worked out as to how to best make the installation in a going plant.

Gradation

Lack of acceptance of standard gradation specifications for aggregate is the prime cause of waste and inefficiency in aggregate production. The processing and stockpiling of aggregate of relative small differences in grading to comply with specifications of different agencies for the same use is far too prevalent a practice. Often a producer will set up his plant to make a grading to meet one specification and when sufficient material is in stockpile, will change the plant to make another size. If the aggregate in stockpile soon moves to the job, well and good; but if open stockpiles are left to the weather for any period of time, they may become contaminated and be rejected; then the material has to be reprocessed.

Simplified Practice Recommendation[13] for grading of coarse aggregate was promulgated about 25 years ago by the Division of Simplified Practice of the National Bureau of Standards with the sponsorship of the NSGA, NCSA, and NSA. Great progress has been made in having national specification writing bodies adopt them. They are used by ASTM, AASHO, AREA, APWA, U. S. government agencies, and numerous state highway departments. A couple of years ago report was submitted to Committee D-4 on the present use of Simplified Practice Recommendation gradings by the various state highway departments which was to the effect that most of the states were in fairly close agreement with those standards on sizes of aggregate for portland cement concrete, but for other uses, these standards were not being used. In other words, the grading requirements on aggregate for use in bituminous mixtures, surface treatments, base courses, and maintenance were just chaotic as far as conformity was concerned. There is hope that progress in the use of standard sizes may be brought about as the new ASTM specification for bituminous mixes becomes more widely used since this specification is the result of the combined efforts of the ASTM, AASHO, and Asphalt Institute.

The wider use of Simplified Practice Recommendations is constantly being encouraged by the three national aggregate associations because it has great merit in several respects: first and foremost, it eliminates duplication of close sizes, it has been used and is satisfactory, it has a simple meaningful number identification system, and it provides for sound and reasonable tolerances at the top and bottom limits. The ASTM has specifications using Simplified Practice Recommendation sizes for portland cement concrete, bituminous paving mixes, surface treatments, and base course material.

Probably the greatest departure from Simplified Practice Recommendations is in the matter of tolerances. Tolerances are a prime requirement for determining the cost of any manufactured article or processed material. A number of years ago, Severinghaus of Consolidated Quarries made a study of the effect of different grading requirements for railroad ballast. The rate of production of the standard AREA grading was 200 tons per hour and for the most restrictive grading the rate was reduced to 65 tons per hour. It is quite probable that many producers are not fully aware of the effect of tolerances on the rate of production, and consequently the cost, because few break down their cost for each size made. This matter of reduction in tolerance may best be explained by an example with surface treatment aggregate, 1/2 in. to No. 4:

Sieve Size	Total Per Cent Passing	
	A-Simplified Practice	B-State Specifications
3/4 in.	100	100
1/2 in.	90–100	100
3/8 in.	40–70	40–70
No. 4	0–15	0–15
No. 8	0–5	—
No. 10	—	0–2

In producing the top size in grading A, a 5/8 or 9/16 in. opening screen may be used, but in producing the top size in grading B a sieve with a 7/16 in. opening would most likely be used because there is no tolerance on this maximum

size. On the fine end of the gradings more tons per hour can be screened with a 5 per cent tolerance than a 2 per cent tolerance. Furthermore, the 2 per cent tolerance may be all right where a purchasing agency has an inspector at the plant to accept material. If inspection is made on the job after one or more rehandlings, there is appreciable risk that a sample may fail to meet the specifications due to segregation and chipping.

It was said that the limitation of not more than 2 per cent passing the No. 10 sieve was for the purpose of controlling the dust. If dust is the objectionable material, the specifications should be written to control dust by specifying the allowable amount to pass a No. 200 sieve.

Deleterious Substances

Nearly all specifications for aggregate contain a paragraph on deleterious substances which, from a production point of view, have seemed innocuous because soundness requirements usually suffice. Yet, this paragraph may be described as a "catch all" and all requirements under its heading should be considered important and should be studied carefully as to their possible effects on production. The purpose of having limitations on deleterious material probably was to prevent disfigurement of concrete surfaces caused by pop-outs due to such material as clay balls, unsound chert, shale, soft pieces, coal, and lignite. These materials would all fail in a soundness test; however, the allowable loss in the soundness test may be 12 per cent, while for deleterious materials it is usually 1 per cent, except for soft pieces which may be 5 per cent. This brings up the problem of interpretation of specifications. Often material that meets the soundness requirement will be accepted, but if pop-outs occur and often these will appear after one winter in service, the requirements with respect to deleterious material are enforced to the letter. The removal of deleterious material has led to the application of beneficiation in gravel operations and selective quarrying in crushed stone operations.

Efforts have been made to develop a test for measuring soft pieces. The one that was thought to offer the most promise was the scratch hardness test, ASTM C 235-57T, which consisted of determining if a small brass rod would scratch the aggregate. At the recent meeting of ASTM Committee C-9, this method of test was referred back to the subcommittee for further study as being without sufficient supporting data to be considered for use as an acceptance test; consequently, it may be said that a satisfactory test for soft pieces is non-existent.

Often found under deleterious substances is the limitation of 1/2 to 1 per cent on the amount of dust or material finer than the No. 200 sieve. It is necessary to have quite clean aggregate for surface treatment work, but for other uses the specifications may be unduly restrictive. Goldbeck[14] in his investigation of the effect of dust coated stone on the strength of concrete concluded that the average decrease in modulus of rupture was 1 per cent for each per cent of dust and the average decrease in compressive strength was 1.3 per cent for each per cent of dust. The maximum dust content investigated was 5.7 per cent.

Rhodes and Finney[15] report marked reduction in durability of concrete which had 85 lb per cu yd of limestone dust as an admixture. This calculates to be slightly over 4 per cent dust in terms of the quantity of coarse aggregate used. Probably the limits in the ASTM Specifications for Concrete Aggregates, C 33, of not more than 1.0 per cent shall be finer than the No. 200 sieve with a note that, if the fines are dust of fracture, the limit may be increased to 1.5 per cent, is correct for concrete aggregates. In bituminous paving mixes, rarely are there close limitations on dust; for example, a typical grading requirement on material passing No. 200 sieve may be 2 to 8 per cent which in the design of the mix may be composed of dust of fracture and mineral filler. However, most specifications on bituminous mixes contain a statement prohibiting aggregate with clay or other objectionable coatings. In any event, the aggregate industry would prefer to have specifications state specific limitations on objectionable characteristics such as shape of particle and deleterious substances such as dust, than to have set forth in its specifications requirements as to the method of processing.

One other requirement is now appearing under deleterious substances which affects few aggregate operations, but those that are affected have a complex problem of great seriousness. This is the chemical reactivity of certain forms of silica in the aggregate with the alkalies in the cement which may result in excessive expansion of the concrete. There are tentative methods of test for determining if an aggregate is potentially

reactive; however, Lerch[16] in discussing the various methods said—"The most reliable methods currently available require such a long time to provide significant results that they are not suitable for acceptance tests. The rapid test provides valuable information that can be used to identify the presence of reactive constituents in the aggregate, but they do not always give assurance that the reactive material is present in the proportion necessary to cause abnormal expansion." If an aggregate is reported to be potentially reactive, a thorough study should be made to determine the most economical method to eliminate any abnormal expansion by the use of admixtures, low alkali cement, or other means.

It, therefore, should be obvious that the requirements for deleterious substances should not be passed over casually, but should be evaluated in all respects that may affect production.

Summary

It should be self evident that specifications for aggregate are based on engineering judgment which is a compromise of research data, and experience, with availability and economics. No numerical limitation in a specification separates good from bad. Any number could be increased or decreased a small amount without effecting a noticeable change in performance. Any change in a specification will create trouble for some segment of the industry and help another. Therefore, changes should be made only when all of the facts are carefully weighed. There is a definite trend at the present time toward far more rigid enforcement of all the requirements of the specifications for aggregates.

Specifications affect production of aggregate in three fundamental aspects which may be grouped as before production, during production, and after production.

Before production

It is essential to determine certain basic qualities of an aggregate source before any material is produced. These specification requirements are for abrasion loss, soundness, and freedom from excessive amounts of deleterious material.

During production

It is necessary to have control over such items as shape of particle, dust (material finer than No. 200 sieve), and gradation.

After production

If an aggregate shows evidence of unsatisfactory performance at any time after a structure has been built, an investigation may be made to determine the cause of the distress. If the study should indicate that the poor performance was due to such characteristics of the aggregate as an excess of chert, shale, soft pieces, or the presence of any other deleterious material, the producer may be told that the objectionable material must be removed to within safe usable limits before any more aggregate will be accepted. It should be obvious, therefore, that to be efficient, one should be technically well informed about the use of his product and exert eternal vigilance to see that it is processed to be within the specifications in every respect.

(Continued on page 20)

Alfred J. Cayia
1893-1961

It is with deep regret that we announce the death on April 3, 1961 of Alfred J. Cayia, for many years importantly identified with the National Crushed Stone Association.

Mr. Cayia was elected to the Board of Directors of the Association in 1941 and served continuously through 1957 when he retired as President of the Inland Lime and Stone Company of Manistique, Michigan. During the period of 1952 through 1957 he enjoyed the distinction of serving as Regional Vice President of the Association for the Northern Region, which includes the States of Michigan, Minnesota, Montana, Nebraska, North Dakota, South Dakota, and Wisconsin. Mr. Cayia joined the Inland Steel Company in 1928, and prior to that time he had been associated with the M. A. Hanna Company of Cleveland, Ohio.

Thoughtful and analytical in his approach to industry problems, his counsel and advice during his service on the NCSA Board proved of great value.

Our deepest sympathy is extended to his family and business associates.

Let's Finish the Job on Time[1]

By ***REX M. WHITTON***
Federal Highway Administrator
Bureau of Public Roads
U. S. Department of Commerce
Washington, D. C.

THIS is my maiden speech as Federal Highway Administrator. I might say at the outset that I approach this job with humility and with acute awareness of the problems ahead. It is a tremendous challenge to me personally and I accepted it with the full knowledge that there is no instant panacea for the trouble besetting the highway program. I must say also that it should not be thought unusual that we are encountering problems and troubles in view of the program's varied effects on the people and the great amount of money involved.

It might be expected that this would be a time for new pronouncements of policy as to the future speed and direction of the federal-aid highway program. As to the Administration's views on these matters, I believe they were set forth quite clearly and forcefully by the President in his Special Message of February 28 to the Congress. Let me say on my own, though, that I foresee no drastic changes in the program as we know it.

I believe the national system of interstate and defense highways can and must be completed in 1972. This was the original intent of Congress in hammering out, amid compromise and controversy, the trail-blazing Federal-Aid Highway Act of 1956. Let us admit that the Act was not perfect. Let us admit, too, that the estimate of cost upon which the financing was based had defects. Then let us go ahead, with the defects corrected, and finish the job on time.

This is a time for those of us involved in the highway program to analyze the remaining problems and—within our appropriate spheres—to do our best to solve them, or at least to suggest solutions.

Basic Problems to be Faced

What are the problems ahead? There are three sensitive areas, I believe, although it is difficult to isolate one from the other. The three are closely intertwined and the resolution of one necessarily eases the others.

First, there is the problem of additional financing to complete the interstate system on time and continue what we call the regular federal-aid program at the necessary level.

Second, there is the problem of so-called "scandals" in the highway program.

Third, there is the problem of public apathy, or at least a lack of full appreciation of the urgent need for the highway program and its benefits.

Financing

As to financing, it is no secret that to complete the interstate system by 1972 and continue the ABC program at the proper level will require additional authorizations of $11.6 billion and additional revenues of nearly $10 billion into the highway trust fund. These are substantial sums even in an era when astronomical figures are commonplace. Considered as investments in the future of America, however, they are relatively small.

The President, in his Special Message on Highways, discussed these benefits in some detail. He spoke of the lives saved, the injuries prevented, the economic stimulus, the spur to employment, the reduced transportation costs made possible by a good highway network. But I think the statement that may make the deepest impression on all of us as individuals and motorists is this one, and I quote the President:

> "It has always struck me as ironic that so many of our citizens—so ingenious in quickly devising ways of ending almost every minor irritant—would so readily tolerate every morning and evening the incredible congestion of our antiquated highways that takes a heavy toll in automotive costs and depreciation, to say nothing of human nerves and tempers."

No doubt the principal features of the financing plan he proposed to Congress are familiar to all of you now. In general it would continue the federal gasoline tax at 4 cents per gallon, raise

[1] Excerpt from remarks presented at the 59th Annual Convention. American Road Builders' Association, Atlantic City, N. J., March 6, 1961

the diesel fuel tax from 4 to 7 cents per gallon and increase present levies on tires, innertubes, tread rubber, and gross weight of heavy trucks. The scheduled transfer of certain excise tax revenues from the general fund to the highway trust fund would be rescinded.

Such a program would provide sufficient revenue to complete the interstate system by 1972 while permitting a rise in the ABC program by $25 million every two years beginning in 1964 until the $1 billion level is reached and maintained.

I recognize the honest differences of opinion that may arise as to the best means of accomplishing these objectives. I believe most people will agree, however, that to stretch out or cut back the program is no solution at all. The House Ways and Means Committee and the Senate Finance Committee must consider this question as part of the larger question of raising sufficient revenue for the support of the government and its programs. In helping these groups in their deliberations I consider it the duty of all interested citizens and organizations to present their ideas on financing.

My own feeling is well known. I believe the public interest requires the completion of the interstate system in accordance with the original timetable and the construction of the ABC program at a slightly increased level. I believe the program should be financed on a pay-as-you-go basis in accordance with the general principles of the 1956 legislation.

Obviously, the program should advance at a predictable level. An orderly, well managed program of the scope of our highway effort is very conducive to efficiency—for state highway departments, for contractors, and for suppliers of equipment and materials. If we can anticipate the amount of work to be done for a reasonable period, the cost of doing it will be lessened. We will get more highway service for our dollar.

Protecting Public Investment

Another troublesome problem is in the area of scandals and unwise procedures which have given all of us cause for concern. Actually, when considered in the light of the magnitude of the job, the irregularities have involved a very small number of public employees and a very small percentage of the public funds invested. This is not to say that any fraud, collusion or theft is right or justifiable. . . . Nor does it diminish the federal-state responsibility to use all feasible means of detecting them.

Public Information

The third problem I would mention in these brief remarks is in the field of public information. Quite obviously our efforts in this direction must be stepped up—at both the federal and state levels and among the organizations which carry the highway message to the grass roots. There is no question that the state highway departments and the Bureau of Public Roads have made tremendous strides in public information and public relations in recent years. But I think we can and must do better. I hope to increase and improve our own public information efforts in the Bureau and to render greater assistance to the states in this field than we have been able to do in the past. Successful operation here would be most helpful in clearing up the other problems. In doing so, of course, we will continue to observe and respect the federal-state partnership which applies to public information as to other fields.

These are the big problems. I have avoided mentioning the many little ones.

Conclusion

In closing I want to thank this organization and its membership for the support you have given the highway program. I appeal for your continued support—not only because the program means more contracts, more sales, more profits—but because it is urgently needed for an expanding economy and the national security.

I also ask your understanding and tolerance in those areas not directly involved in the business of building roads. Such a tremendous program has impacts on other phases of government operations. It affects community development in many ways. It frequently causes hardships and dislocations. It cannot be separated from other means of transportation. In brief the interstate and other federal-aid highways must be fitted into the over-all pattern of urban renewal, housing and the total transportation needs of the communities.

Finally, I appeal to you for continued and strengthened support in policing those areas of the highway program which fall within your own operations. If we can make the public image of the program come through strong and clear and as nearly simon-pure as is humanly possible, then I believe the necessary financing will be made available and we can proceed with vigor and assurance to finish the job on time. /NCSA

Petrographical Aspects of the Polishing of Natural Roadstones*

By DIANE C. KNILL

The relation between the petrology and polished-stone coefficient of various natural roadstones, which have been polished in an accelerated-wear machine at the Road Research Laboratory, is discussed. The mineralogy, the variation in hardness of the constituents, the texture and the amount of alteration all appear to be connected with the degree of polish which the rock acquires during the test. These factors variously affect the different roadstone groups.

Introduction

IN A series of investigations by officers of the Road Research Laboratory, it has been recently demonstrated that the degree of slipperiness of road surfaces is directly related to the type of roadstone utilised in the surfacing. Certain rocks are highly resistant to polishing whereas others polish easily under traffic and hence are dangerous, especially when wet. In order that the danger due to slipperiness on heavily trafficked roads may be minimized, the rate and degree of polishing of the various British roadstones were investigated at the Road Research Laboratory. Briefly, the experimental procedure for producing an artificially polished surface is as follows: the specimens for the tests are made from about forty 3/8 in. rock chippings held in a sand-cement mortar with their outer surfaces projecting just above the mortar. The specimens are mounted on the periphery of a wheel which is rotated at a speed of about 320 rpm. The surface of the specimens is held in contact with a pneumatic-tyred wheel with a contact pressure of 70 psi. During the test, which lasts for 6 hr, various grades of abrasive are fed between the tyre and the specimens. The degree of polish of the specimens is assessed by measuring their frictional resistance to the passage of a rubber slider mounted on the bob of a pendulum. The frictional resistance is expressed as the 'polished-stone coefficient' which ranges from 0.30 to 0.80, the most highly polished specimens having a low value of 0.30, the roughest a polished-stone coefficient (P) of 0.80. The main results of the investigation with the experimental procedure and discussion of the results were reported by MacLean & Shergold.[1] The results were summarized as follows. 'All rocks of the gritstone group tested remained rough at the end of the test. The flints, hornfels, limestones and slags polished to different degrees, the limestones and slags covering quite a wide range from smooth to rough. Stones within the basalt, gabbro, granite, porphyry and quartzite groups all gave a range of polished-stone coefficients intermediate between extreme smoothness and extreme roughness.'

Although correlations between the physical properties and petrology of roadstones have been made by various authors,[2-5] the polishing of roadstones in relation to petrology has not been discussed. This paper summarizes the results of an investigation undertaken in the hope that it would be possible to establish a relation between the polishing of roadstones and their petrographical characteristics. In any assessment of roadstone, however, it is important to realize that the polished-stone coefficient constitutes but one of the physical properties of roadstones.

Experimental

All the roadstones examined in this study had a polished-stone coefficient which had been determined at the Road Research Laboratory.

In essence, it was found that the factors which influence the degree of polish obtained on specimens during the test appear to be the proportion and hardness of various minerals present, the mineral fabric and the grain size. These factors vary in importance between different rock groups and hence in the following account each group is considered individually. Table I lists the rock types included in the various groups B.S. 63: 1951, and in Table II the specimens in each group have been arranged in order of increasing polished-stone coefficient.

*Reprinted by permission of the Director, Geological Survey and Museum, London, England

Two of the most important physical characteristics, hardness and cleavage, of the common minerals of the British roadstones from the standpoint of their polishing are shown in Table III. Hardness as applied to crystals refers to the resistance offered to the production of a scratch on a smooth surface. All grades of hardness exist from talc to diamond, the hardest natural mineral. Mohs' scale, in order of progressive hardness is expressed as follows: 1 talc; 2 gypsum; 3 calcite; 4 fluorite; 5 apatite; 6 orthoclase; 7 quartz; 8 topaz; 9 corundum; 10 diamond.

TABLE I
GROUP CLASSIFICATION OF NATURALLY-OCCURRING ROCKS

Basalt group
- Andesite
- Basalt
- Basic porphyrite
- Diabase
- Dolerites of all kinds including theralite and teschenite
- Epidiorite
- Hornblende-schist
- Lamprophyre
- Quartz-dolerite
- Spilite

Granite group
- Gneiss
- Granite
- Granodiorite
- Granulite
- Pegmatite
- Quartz-diorite
- Syenite

Flint group
- Chert
- Flint

Schist group
- Phyllite
- Schist
- Slate
- All severely sheared rocks

Porphyry group
- Aplite
- Dacite
- Felsite
- Granophyre
- Keratophyre
- Microgranite
- Porphyry
- Quartz-porphyrite
- Rhyolite
- Trachyte

Gabbro group
- Basic diorite
- Basic gneiss
- Gabbro
- Hornblende-rock
- Norite
- Peridotite
- Picrite
- Serpentine

Hornfels group
- Contact-altered rocks of all kinds except marble

Limestone group
- Dolomite
- Limestone
- Marble

Gritstone group
- Agglomerate
- Arkose
- Breccia
- Conglomerate
- Greywacke
- Grit
- Sandstone
- Tuff

Quartzite group
- Ganister
- Quartzitic sandstones
- Re-crystallised quartzite

TABLE II
TYPES STUDIED IN THE VARIOUS ROCK GROUPS AND THEIR EXPERIMENTALLY ESTABLISHED POLISHED-STONE COEFFICIENTS (P)

Rock type	P
Basalt group	
Dolerite	0.45
Basalt	0.45
Olivine-analcite-dolerite	0.50
Dolerite	0.50
Dolerite	0.50
Hornblende schist	0.50
Diabase	0.50
Basalt	0.50
Andesite	0.55
Dolerite	0.60
Diabase	0.60
Basalt	0.60
Basalt	0.65
Dolerite	0.70
Diabase	0.70
Metadolerite	0.70
Gritstone group	
Breccia	0.60
Greywacke	0.60
Siltstone	0.65
Sandstone	0.65
Quartzose grit	0.65
Sandstone	0.70
Feldspathic sandstone	0.75
Siltstone	0.75
Sandstone	0.75
Greywacke	0.80
Porphyry group	
Felsite	0.45
Microgranodiorite	0.45
Porphyrite	0.50
Biotite - hornblende - porphyrite	0.50
Keratophyre	0.50
Felsite	0.50
Trachyte	0.55
Pyroxene-granophyre	0.55
Porphyrite	0.55
Limestone group	
Limestone	0.30
Limestone	0.35
Limestone	0.35
Limestone	0.35
Limestone	0.35
Dolomite	0.40
Oolitic limestone	0.40
Dolomite	0.40
Limestone	0.40
Dolomite	0.40
Limestone	0.45
Dolomite	0.45
Limestone	0.50
Limestone	0.55
Sandy Limestone	0.55
Flint group	
Flint	0.30
Flint gravel	0.35
Flint	0.40
Gabbro group	
Hornblende-gabbro	0.50
Gabbro-norite	0.50
Hornblende-biotite micro-diorite	0.50
Picrite	0.50
Hornblende-gabbro	0.50
Sericitised diorite	0.55
Diorite	0.60
Gabbro	0.65
Granite group	
Tonalite	0.45
Granodiorite	0.50
Monzonite	0.50
Granite	0.55
Tonalite	0.55
Granite	0.55
Quartz-diorite	0.65
Quartz-diorite	0.65
Quartzite group	
Quartzite (gravel)	0.45
Quartzite	0.55
Quartzose sandstone	0 55
Quartzite	0.60
Hornfels group	
Hornfelsed diabase	0.50
Hornfels	0.50
Hornfels	0.50

Results

BASALT GROUP

An attempt to correlate the physical and petrological properties of the quartz-dolerites and tholeiites has been made by Sabine *et al.*[6] The polishing of roadstones was, however, not dealt with in that account. These authors found no general correlation between mineral content or grain size and results of physical tests, but considerable correlation existed between test values and the geological occurrence.

TABLE III

HARDNESS AND CLEAVAGE OF VARIOUS MINERALS COMMONLY FOUND IN NATURAL ROADSTONES

Mineral	Hardness (on Mohs' Scale)	Cleavage (in relation to crystallographic axes on Miller's scale)	Mineral	Hardness (on Mohs' Scale)	Cleavage (in relation to crystallographic axes on Miller's scale)
Kaolinite	2—2.5	perfect (001)	Pyroxene group (augite, etc.)	5—7	good prismatic cleavage
Chlorite group	2—2.5	perfect (001)	Feldspar (orthoclase, plagioclase, etc.)	6—6.5	good (001) and (010) perfect basal cleavage
Muscovite	2.5—3	perfect (001)	Chalcedony	6	—
Biotite	2.5—3	perfect (001)	Epidote group	6—7	perfect (001)
Calcite	3	perfect (1011)	Olivine group	6.5—7	distinct (010) less distinct (100)
Dolomite	3.5—4	perfect (1011)	Garnet group	6.5—7.5	—
Zeolites	3.5—5.5	fibrous or columnar	Quartz	7	—
Amphibole group (hornblende etc.)	4—6.5	well-developed prismatic cleavage	Cordierite	7—7.5	distinct (010) poor, (100) and (001)
			Sillimanite	7.5	perfect (010)

Forty-six samples from 16 quarries in Great Britain have been examined petrologically in the present investigation of this group. The polished-stone coefficient (*P*) for rocks in this group is very variable, 0.45-0.70. The results of the examination of this group, Table IV, may be summarized as follows:

1. *P* appears to rise, i.e., the rock becomes rougher, when minerals having different hardness are present. Those dolerites or basalts consisting dominantly of fresh ferro-magnesian minerals and plagioclase generally have a low *P* since these minerals have approximately the same hardness. Any sericitisation of plagioclase or alteration of an augitic ground-mass increases the degree of roughness because an assemblage of hard and soft minerals does not polish uniformly. Provided that the augite and plagioclase remain fresh, serpentinization of olivine phenocrysts appears to be unimportant.
2. A non-foliated holocrystalline groundmass consisting of a plexus of plagioclase laths, with or without interstitial augite, decreases *P* whereas if the groundmass is foliated or fluxioned the coefficient increases. Ophitic rocks do not appear to be rougher than other types and, unless the ground mass is moderately altered, the effect of a porphyritic texture on roughness appears to be negligible.
3. The proportion and hardness of secondary minerals in relation to unaltered primary minerals variably influences roughness. Soft minerals, e.g., sericite, chlorite, kaolinite, etc., generally raise *P* whereas harder minerals such as epidote, lower the value.
4. *P* is increased by the presence of shattered fresh ferro-magnesian minerals or feldspar. Presumably such shattered grains are weak and tend to be plucked out.
5. Scattered grains of opaque ore minerals appear to increase *P* especially when they are finely disseminated.
6. The effect of grain size on *P* appears to be small although there is a tendency for coarse-grained material to have a higher value.

In this group the most resistant rock to polishing would appear to be a moderately altered, relatively coarse-grained one and *P* for this type will probably be greater than 0.60.

TABLE IV

CORRELATION BETWEEN POLISHED-STONE COEFFICIENT (P) AND THE PETROGRAPHY OF TESTED SPECIMENS IN THE BASALT GROUP

Rock Type	P	Average Grain Size, mm.	Texture	Mineral or Texture Proportions (approx.)	Relative Amount of Alteration of Rock
Basalt	0.45	0.1—0.5	Porphyritic with allotriomorphic groundmass	f: rest: : 1: 1	slight
Dolerite	0.45	1.0	Subophitic	f: pyx: : 1: 1	slight
Olivine-analcite-dolerite	0.50	0.7—1.0	Hypidiomorphic	f: pyx: : 1: 1	slight
Dolerite	0.50	0.3	Allotriomorphic	f: pyx: : 1: 1	slight
Dolerite	0.50	0.3	Hypidiomorphic	f: pyx: alt: : 1: 1: 2	majority of constituents altered
Hornblende-schist	0.50	0.3	Schistose	hbl: f: : 1: 1	slight
Diabase	0.50	0.1	Ophitic	f: pyx: : 1: 1	slight
Basalt	0.50	0.5—1.0	Porphyritic	ph: gm: : 1: 4	slight
Andesite	0.55	< 0.1	Porphyritic	ph: gm: : 1: 10	moderate
Dolerite	0.60	0.8	Hypidiomorphic	f: rest: : 1: 1	moderate
Diabase	0.60	0.5	Hypidiomorphic	f: pyx: alt: : 3: 2: 1	moderate
Basalt	0.60	< 0.2	Ophitic	f: pyx: : 1: 1	slight
Basalt	0.65	< 0.1	Trachytic	f: pyx: : 4: 1	high
Diabase	0.70	0.6	Allotriomorphic	f: pyx: : 1: 1	high
Dolerite	0.70	0.6	Ophitic	f: pyx: : 1: 1	moderate
Metadolerite	0.70	0.3—0.5	Ophitic	ph: gm: : 1: 5	high

Abbreviations: — f = feldspar; pyx = pyroxene; alt = altered minerals; ph = phenocrysts; gm = ground-mass; hbl = hornblende

GABBRO GROUP

Rocks from nine quarries were examined, *P* for the tested specimens ranging from 0.50 to 0.65. The rock types included gabbro, hornblende-gabbro, diorite and a single picrite. On average the diorites appear to have a higher coefficient than the gabbros although one gabbro had a polished-stone coefficient of 0.65, see Table II. Factors affecting *P* in this group appear to be:

1. The presence of minerals of different hardness leads to a corresponding increase in *P*.
2. The grain size of the amphibole present (common hornblende) appears to be important. Those specimens in which hornblende occurs in large crystals have lower *P* than those in which the hornblende occurs in fibrous aggregates or crystal felts, since in the latter case a roughly textured surface with few large cleavage planes is present.
3. The extent and nature of the alteration of the plagioclase directly affects *P*. When the feldspar is replaced by soft sericitic or micaceous minerals the coefficient is higher than when saussuritisation of the feldspar occurs, presumably since the softer minerals are polished and worn away more readily. Similarly an increase in serpentinisation or uralitisation of the ferro-magnesian minerals increases the polished-stone coefficient.

GRANITE GROUP

P for specimens from this group range between 0.45 and 0.65 but are generally 0.50 or higher, Table II. Specimens were examined from eight quarries and included the following rock types: granite, granodiorite, tonalite, monzonite and quartz-diorite. Two quartz-diorites had the highest *P* (0.65), Table II.

The reasons for the variability in polishing in this group are difficult to ascertain. The various characteristics are outlined in Table V. There does not appear to be any correlation between *P* and the average grain size. The latter, which is often difficult to estimate, ranges in the specimens examined from 0.5 to 2 mm.

In this group the majority of the rocks examined are moderately or severely altered but there seems to be no correspondence between the amount and type of alteration and *P*. With few exceptions the rocks have been chloritised or epidotised and secondary hornblende and quartz-feldspar intergrowths are common. None of these features appears to influence *P*.

Two specimens of quartz-diorite, $P = 0.65$, are composed of an allotrimorphic granular intergrowth of heavily saussuritised plagioclase accompanied by pale-green or colourless epidote, interstitial quartz, quartz-feldspar intergrowths and partly exsolved titaniferous ore. Patches of epidote and chlorite probably represent the orig-

TABLE V

CORRELATION BETWEEN POLISHED-STONE COEFFICIENT (P) AND THE PETROGRAPHY OF TESTED SPECIMENS IN THE GRANITE GROUP

Rock Type	P	Average Grain Size, mm.	Relative Amount of Alteration of Rock	Secondary Minerals			Quartz-Feldspar Inter-growths
				Epidote	Hornblende	Chlorite	
Tonalite	0.45	0.7	slight	−	+	+	−
Granodiorite	0.50	1—2	moderate	+	−	−	+
Monzonite	0.50	0.5	moderate	+	+	+	+
Granite	0.55	0.5—1.0	slight	+	−	+	+
Tonalite	0.55	1—1.5	moderate	+	+	+	−
Granite	0.55	1—2	slight	+	−	−	+
Quartz-diorite	0.65	1	severe	+	+	+	−
Quartz-diorite	0.65	0.5	severe	+	−	+	+

inal ferromagnesian minerals. The relatively high value of P is possibly related to the presence of minerals of varying hardness and especially the hard granular epidote and quartz which are embedded in the softer material. Another petrographically similar rock, a monzonite, has a lower P (0.50). One of the granodiorites examined, in which $P = 0.50$, contains numerous brownish euhedral laths of twinned plagioclase, dirty green hornblende, apple-green chlorite with included grains of sphene, scattered grains of opaque ore and chartreuse epidote. The plagioclase is replaced by finely divided mica or turbid epidote. A graphic intergrowth of quartz and feldspar occurs interstitially, the latter replaced by finely-divided mica. In this specimen the varying degree of hardness of an assemblage of minerals does not appear to have any direct bearing on the low value of P.

At present no definite conclusion can be drawn with regard to the relation existing between polishing and petrology within this group, and no estimate of the coefficient can be attempted from a petrographical study alone.

Porphyry Group

Specimens of roadstones which have had polishing tests carried out were examined from nine quarries. P in this group tends to range from intermediate to low and out of the nine quarries examined six gave a value of 0.50 or less, the remaining three a coefficient of 0.55.

Typically the specimens consist of epidotised acid plagioclase phenocrysts and phenocrysts of quartz, with rarer pyroxene and hornblende, lying in a groundmass which is commonly felsitic but which may also contain variable amounts of chlorite, granular epidote and more coarsely crystalline quartz and kaolinised feldspar, the last two occasionally graphically intergrown. A felsitic groundmass and the presence of interstitial quartz and granular epidote probably cause a decrease in the polished-stone coefficient, whereas when abundant chlorite, mica and kaolinised alkali-feldspar are present the coefficient increases. This probably arises because the felsitic groundmass, the quartz and epidote wear in a similar fashion to give a smooth surface, whereas the chlorite, mica and kaolinised alkali-feldspar are softer and wear away more easily, leaving a rough surface. Grain size is not noticeably important although the coarser-grained varieties tend to have slightly higher P values. Granulitised and sutured crystal boundaries appear to produce a strong coherent rock which polishes even if it contains a reasonable proportion of soft minerals.

The petrology of the members of this group explains the experimental results and leads one to expect P to have an intermediate value, Table II. Not only are the proportions of hard and soft minerals approximately equal but those minerals with a hardness greater than 5 (i.e., epidote, pyroxene, quartz, etc.) are usually found as phenocrysts or scattered grains in a fine-grained decomposed groundmass which wears away.

Hornfels Group

As the number of quarries in rocks of this group which are worked for roadstone is limited, the

amount of material available for examination is necessarily scarce and hence the conclusions drawn may be of limited validity. *P* for the material tested was 0.50. The amount of polishing appears to be enhanced by a higher proportion of minerals of hardness greater than 5, e.g., amphibole, fresh feldspar and quartz and variable amounts of garnet, cordierite, sillimanite, etc. Furthermore, the hornfels are generally fine-grained and the boundaries of the grains are sutured so that the rock presents a tough well-bound cohesive surface.

Schist Group

Since the Schist group is not commonly used for road aggregate in Great Britain, there is no information available on the polishing in an accelerated wear machine of members of this group. It is not expected that the value of *P* for such rocks would be high, because many of the minerals are soft and flaky.

Flint Group

Material from only three quarries was examined and owing to the uniform nature of this rock type the degree of polish was high, Table II. This is presumably due to three principal factors: (1) the crypto-crystalline siliceous nature of the material which is firmly bonded and hence is not friable; (2) the simple mineral composition and uniform hardness, approx. 7; (3) the high resistance to attrition, Phemister *et al.*[5]

Quartzite Group

Material from four quarries has been tested, *P* values ranging between 0.45 for crushed gravel and 0.60 for crushed quartzite, Table II. The specimens consist of sub-angular or sub-rounded quartz grains, angular fragments of granulitised quartzite, sub-rounded grains of kaolinised feldspar, perthitic microcline and sporadic fragments of micropegmatite. Contiguous outgrowth rims of quartz form the cement and obscure much of the original rounding of the grains. Straining of the quartz grains is common. Those features which would appear to influence *P* are:

1. Kaolinised feldspars and fragments of granulitic quartzites probably break or crush easily and tend to be pulled out from the more resistant matrix.
2. The actual strength of bonding between the quartz grains and their contiguous quartz rims is unknown. If the bonding is weaker than has previously been supposed, the quartz grains may pluck out the siliceous matrix in which they lie.
3. Micaceous minerals if present in moderate amounts probably facilitate the breakdown of the quartzite and increase *P* owing to their relative softness and good basal cleavage.

Gritstone Group

Members of this group have high *P* values, which did not fall in the samples below 0.60 and rose to 0.80, Table III. Although the rock types included in this group are variable they are all allied in being clastic sediments. The rocks consist of the following materials: sub-rounded, sub-angular or angular quartz and feldspar grains, lithic fragments, variable amounts of argillaceous material and carbonate, rounded heavy detrital minerals including zircon, rutile and tourmaline, and scattered grains of opaque minerals, especially pyrite. The matrix is wholly or partly calcareous, argillaceous or siliceous.

It is easy to see why *P* for this group is so high, since under wear hard crystals and lithic fragments are merely pulled out of the generally soft and friable matrix. Grain size of the components does not appear to be very important although the coarse members of this group, breccias, conglomerates, etc., were not studied, and very coarse material would be broken into rock fragments before being used as a roadstone. Other factors influencing the coefficient appear to be the percentage of kaolinised feldspar and the presence of any structural weakness such as cracks in fragments and crystals: both of these features appear to increase *P*.

Where sediments are highly compacted and composed of mineral grains of uniform hardness, they may be expected to polish considerably although the time taken will vary with the hardness of the mineral. Loosely compacted rocks are more friable and hence the particles are easily pulled out of the incoherent matrix producing a rough surface.

Limestone Group

The polishing of roadstones within this group has been investigated by Dr. P. A. Sabine, unpublished report, Road Research Laboratory, 1956, who concluded that the following features ex-

erted some control on the polishing of limestones and dolomites.

1. Specimens containing small rhombs or granules of dolomite tend to polish less easily since under slow chemical attack, e.g., atmospheric agents, the 'greater time taken for the dolomite to dissolve would allow other factors to assume greater importance and in consequence the dolomites would be expected to show less polish.'
2. For the stone, i.e., limestone, to retain a rough surface under wear it should contain insoluble grains of quartz, feldspar, etc., and these grains should preferably be coarse.
3. No correlation was found between the grain size of the rocks and their degree of polish but those composed of small rhombs or with a finely granular texture in the ground-mass are rougher than those with a ground mass of interlocking calcite plates of variable size.

The author's results, Table VI, are in fairly close agreement with those of Sabine given above although it is not considered that the proportion of dolomite is as important as he suggests. For rocks in which the calcite or dolomite is present in plates or in a coarsely crystalline mosaic, *P* is low, presumably since a single large cleavage face polishes more readily than a fine-grained mosaic.

TABLE VI
CORRELATION BETWEEN POLISHED-STONE COEFFICIENT (P) AND THE PETROGRAPHY OF SPECIMENS TESTED IN THE LIMESTONE GROUP

P	Average Grain Size, mm.	Organisms	Coarse Crystalline Carbonate Patches	Insoluble Residue, Per Cent
0.30	0.02	sparse	+	1.90
0.35	0.25	—	+	1.42
0.35	0.02	sparse	+	1.40
0.35	0.02	sparse	+	2.30
0.35	0.26—0.28	sparse	−	—
0.40	0.1	sparse	+	9.80
0.40	0.035	—	+	2.80
0.40	0.19—0.28	—	−	4.60
0.40	0.02—0.03	frequent	+	—
0.40	0.08—0.10	—	−	3.10
0.45	0.02—0.03	sparse	+	1.26
0.45	0.09	—	−	2.30
0.50	0.02—0.03	sparse	+	5.00
0.55	0.02	plentiful	−	3.70
0.55	0.02	plentiful	+	36.0

In fact, those rocks which polish least appear to be calcilutites, i.e., consolidated carbonate muds. Furthermore, specimens which contain fossils generally have a moderate *P* of 0.55. Clastic limestones have a higher *P* since they consist of organic and lithic fragments which pull out of the matrix of soft carbonate mud.

Recapitulating, the most satisfactory limestones are undoubtedly calcilutites, calcite-mudstones, and possibly clastic limestones. In addition, *P* may be increased by the amount of insoluble residue present, especially if such residue is quartz. However, the presence of even small patches of medium- or coarse-grained carbonate is detrimental and increases the degree of polish obtained. It is possible that slip along glide lamellae in the coarser calcite plates is important in polishing and flow caused by the pressure of traffic may be an elusive polishing catalyst.

Conclusion

The apparent relation between the petrology of roadstones and the polished-stone coefficient *P* produced in an accelerated wear machine has been outlined for the various groups of roadstones and the conclusions reached in each group summarized. The Gritstone group is outstanding since *P* is always high, 0.60-0.80, i.e., the rock is rough, whereas in other groups, Basalt, Granite and Quartzite, *P* varies from moderately high, 0.65, to relatively low, 0.45-0.50. Low *P* values characterize the Limestone and Flint groups.

In the igneous rocks, those petrological features which probably affect *P* most readily are a variation in hardness between the minerals, and the proportion of soft minerals present. Rocks in which cracks and fractures are present in the individual mineral grains generally have higher *P* since such grains are weak and pluck out of the matrix. Finer-grained allotriomorphic igneous rocks, provided they are reasonably fresh, present a tough, cohesive surface which polishes considerably. Sedimentary rocks are variable in their behaviour. The Gritstones give a uniformly high *P* since hard crystals and lithic fragments pluck out of a generally soft and friable matrix. The flints being of simple mineral composition, cryptocrystalline and of uniform hardness polish have low *P*. The Limestone group has an average *P* of about 0.4. Higher coefficients, in this trade group, appear to be related to the presence of an insoluble residue, especially if such residue is quartz, and to the presence of coarsely crystalline patches of carbonate. The metamorphic rocks tested included members of the Quartzite and

Hornfels groups. The intermediate value of P in the Quartzite group is due to the presence of altered feldspars and shattered grains of quartz and quartzite plucking out of a more resistant matrix. However those quartzites which have recrystallized to form a voidless quartz mosaic can be expected to polish considerably. The polishing of the hornfels is possibly the result of fine-grain size and the presence of a high proportion of minerals whose hardness is greater than 5 on Mohs' scale, but these observations are based on only three specimens.

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In the March 1961 issue, two of the newly elected members of the Manufacturers Division Board, pictured above, were incorrectly identified. They are reprinted in this issue with the proper titles.

Specifications for Mineral Aggregates

(Continued from page 10)

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Rogers Iron Works Co.
11th and Pearl Sts., Joplin, Mo.
Bins; Castings — Iron; **Classifiers** — Screw, Paddle; **Conveyors** — Belt, Pan; **Crushers, Pulverizers; Drills** — Jumbo; **Drop Balls; Elevators** — Bucket; **Feeders** — Apron, Reciprocating, Belt; **Grizzlies** — Vibrating, Roll; **Hoists** — Mine; **Plants; Screens** — Vibrating, Revolving; **Washing Equipment**

Schramm, Inc.
West Chester, Pa.
Air Compressors; Bits — Rock; **Drills, Drilling Equipment, Supplies; Pneumatic Tools**

Screen Equipment Co., Inc.
40 Anderson Road, Buffalo 25, N. Y.
Screens — Vibrating

Simplicity Engineering Co.
Durand, Mich.
Car Shakeouts; Conveyors — Pan; **Feeders** — Vibrating; **Grizzlies; Screen Sections; Screens** — Vibrating

Smith Engineering Works
Division Barber-Greene Co.
P. O. Box 723, Milwaukee 1, Wis.
Belts — Conveyor, Elevator; **Bin Gates; Buckets** — Elevator; **Classifiers** — Sand; **Conveyors** — Belt; **Crushers; Elevators** — Bucket; **Feeders** — Reciprocating, Apron; **Grizzlies; Plant Design and Layout; Plants; Screens** — Vibrating, Revolving; **Washing Equipment**

Spencer Chemical Co.
610 Dwight Bldg., Kansas City 5, Mo.
Explosives, Blasting Supplies

Stedman Foundry & Machine Co., Inc.
P. O. Box 209, Aurora, Ind.
Crushers, Pulverizers — Cage Disintegrators, Hammermills; **Screens** — Vibrating

Sturtevant Mill Co.
103 Clayton St., Dorchester, Boston 22, Mass.
Crushers, Pulverizers; Separators — Air

Taylor-Wharton Co.
Division Harsco Corp.
High Bridge, N. J.
Buckets — Elevator; **Castings; Chains; Conveyors** — Apron; **Dippers** — Shovel; **Drop Balls; Feeders; Screen Sections; Welding Equipment and Supplies**

Thew Shovel Co.
East 28th St. and Fulton Road, Lorain, Ohio
Loaders — Wheel; **Shovels, Draglines, Cranes, Clamshells**

Thor Power Tool Co.
175 North State St., Aurora, Ill.
Belts; Bits — Rock; **Drills, Drilling Equipment, Supplies; Dust Control Equipment; Hoists** — Drum; **Hose; Motors** — Electric; **Pneumatic Tools; Power Generating and Distributing Systems; Pumps**

Timken Roller Bearing Co.
Service-Sales Division
1835 Dueber Ave., S. W., Canton 6, Ohio
Bearings — Tapered Roller; **Bits** — Rock; **Steel** — Alloy

Torrington Co.
Bantam Bearings Division
3702 West Sample St., South Bend 21, Ind.
Bearings

Traylor Engineering & Manufacturing
Division of Fuller Co.
Allentown, Pa.
Air Compressors; Blowers and Fans; Conveyors — Pneumatic; **Crushers, Pulverizers; Dryers** — Aggregate; **Dust Control Equipment; Feeders; Indicators** — Bin Level; **Plant Design and Layout**

Manufacturers Division – National Crushed Stone Association
(continued)

Trojan Powder Co.
17 North Seventh St., Allentown, Pa.
Explosives, Blasting Supplies

Tyler, W. S., Co.
3615 Superior Ave., N. E., Cleveland 14, Ohio
Screen Sections — Wire Cloth; **Screens** — Vibrating, Shaking, Revolving; **Testing Sieves and Shakers; Vibrators** — Bins and Chutes; **Washing Equipment**

Universal Engineering Corp.
Subsidiary of Pettibone Mulliken Corp.
625 C Ave., N. W., Cedar Rapids, Iowa
Asphalt Plants; Bin Gates; Bins — Portable, Semi-Portable; **Conveyors** — Belt, Pan, Apron; **Crushers, Pulverizers** — Jaw, Roll, Impact, TwinDual Roll, Hammermills; **Elevators** — Bucket, Belt; **Feeders** — Wobbler, Pan, Apron, Vibrating; **Grizzlies; Plant Design and Layout; Plants; Screens** — Vibrating, Shaking, Revolving; **Washing Equipment**

Varel Manufacturing Co.
9230 Denton Drive, Dallas 20, Texas
Bits — Rock

Vibra-Tech Engineers, Inc.
407 Hazleton National Bank Bldg., Hazleton, Pa.
Seismological Instruments, Surveys

Vibration Measurement Engineers, Inc.
725 Oakton St., Evanston, Ill.
Seismological Instruments, Surveys

Webb, Jervis B., Co.
8951 Alpine Ave., Detroit 4, Mich.
Chains; Conveyors — Belt, Apron, Drag, Flight; **Elevators** — Bucket; **Feeders; Plant Design and Layout; Plants**

Werco Steel Co.
2151 East 83rd St., Chicago 17, Ill.
Buckets — Clamshell, Dragline, Elevator; **Castings** — Manganese, Alloy Steel; **Chains; Conveyors** — Belt; **Crushers, Pulverizers; Dippers**—Shovel; **Drop Balls; Screen Sections; Wire Rope and Related Products**

Western-Knapp Engineering Co.
50 Church St., New York 7, N. Y.
Consulting Engineers

White Motor Co.
842 East 79th St., Cleveland 1, Ohio
Batteries; Engines — Gasoline; **Power Generating and Distributing Systems; Tractors** — Truck; **Trucks, Trailers, Truck Bodies**

White Motor Co.
Autocar Division
Exton, Pa.
Trucks, Trailers, Truck Bodies

Wickwire Spencer Steel Division
Colorado Fuel & Iron Corp.
575 Madison Ave., New York 22, N. Y.
Screen Sections — Wire Cloth; **Screens** — Vibrating, Shaking, Revolving; **Wire Rope and Related Products**

Williams Patent Crusher & Pulverizer Co.
2701-2723 North Broadway, St. Louis 6, Mo.
Bins; Classifiers; Crushers, Pulverizers; Feeders; Screens — Vibrating; **Separators** — Air

Wiss & Associates
Division of Engineers Collaborative
570 Northwest Highway, Des Plaines, Ill.
Consulting Engineers; Seismological Instruments, Surveys

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